City of West Lake Hills

Drainage and Erosion Control Design Manual

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CHAPTER 1 INTRODUCTION

The purpose of the Drainage and Erosion Control Design Manual is to establish standard principles and practices for the planning, design, construction, maintenance, and management of stormwater drainage, erosion control, and water quality facilities within the City of West Lake Hills and its ETJ. The policy statements of Chapter 2 provide the underlying principles by which all drainage facilities shall be designed. The application of the policy is facilitated by the technical criteria contained in the remainder of the manual.

1.1 Purpose and Scope

The design factors, formulas, graphs, and procedures described in this manual are intended to serve as guidelines for the design of drainage improvements and projects involving the volume, rate of flow, method of collection, storage, conveyance, treatment, and disposal of stormwater and erosion protection from stormwater flows. Responsibility for actual design remains with the design engineer.

This manual and the City of West Lake Hills Code of Ordinances (City Code) contain requirements for the design of infrastructure related to storm drainage, flood protection, water quality, and erosion control facilities. Where there is any conflict between this manual and the current City Code, the more restrictive shall take precedence. The design engineer is responsible for complying with the latest version of this manual and code adopted by the City.

If conflicts occur between City policy and criteria in this manual versus other regulatory authorities with jurisdiction in the same area, such as TCEQ, FEMA, or TxDOT, then the more stringent requirement will apply.

1.2 Applicability

Stormwater policy and criteria in this manual shall apply to all drainage improvements and projects that may impact drainage or water quality, both publicly and privately funded, within the City and within its ETJ. Definitions, methods, criteria, procedures, and data in this manual have been developed to support the stormwater policy outlined in Chapter 2.

1.3 Waivers

The City Administrator, when petitioned for a waiver, may approve the waiver, deny the waiver, or make an initial determination and refer the matter to City Council for a variance. If the City Administrator approves the waiver, no approval by the City Council is required.

1.4 Amending the Manual

Amendments may be recommended by City Staff and approved, denied, or sent to City Council by the City Administrator. Notification and explanation shall be given to the City Council of all administratively approved amendments. Any member of the City Council may request that the administratively approved amendment be placed on a City Council meeting agenda for discussion and review. If a request for an administratively approved amendment to be placed on a City Council agenda is not received within ten days, the administratively approved amendment will immediately take effect.

1.5 References and Definition of Terms

At certain points in the text, the reader will encounter numbers enclosed in brackets, for example [1]. These numbers correspond to the references listed in Appendix A. Definitions of common terms used in this manual are provided in Appendix B. A list of abbreviations commonly used within this manual is in Table 1-1. For unfamiliar abbreviations not included in Table 1-1, the City of West Lake Hills may be contacted for the appropriate full, formal name associated with the abbreviation.

Table 1-1: List of Abbreviations

Abbreviation	Definition
AASHTO	American Association of State Highway and Transportation Officials
BMP	Best Management Practice
City	City of West Lake Hills
ETJ	Extraterritorial Jurisdiction
FEMA	Federal Emergency Management Agency
FHWA	Federal Highway Association
NRCS	Natural Resources Conservation Service
ROW	Right-of-way
TCEQ	Texas Commission on Environmental Quality
TPDES	Texas Pollutant Discharge Elimination System
TxDOT	Texas Department of Transportation
USACE	US Army Corps of Engineers

CHAPTER 2 DRAINAGE CRITERIA

This manual represents the application of accepted principles of surface drainage engineering and is a working supplement to information obtainable from standard drainage design handbooks, other publications on drainage design, and the City Code. The policy statements of this section provide the underlying principles by which all drainage improvements shall be designed. The application of the policy is facilitated by the technical criteria contained in the remainder of the manual.

2.1 Permit Submittal Components

The submittal components to be provided by the property owner, or agent, are determined by the requirements of this manual. Applications are also located on the City's website.

The development category shall be based on the type of development, impervious cover, and disturbed area of the development as shown in Table 2-1 and Table 2-2. The development category for an application shall be determined by the least restrictive category where all the criteria are met.

Table 2-1: Residential Development Categories

Category	Criteria
Residential Type I Development	No Variances/Special Use Permits; and No work within drainage easements; and < 1,000 SF of additional impervious cover
Residential Type II Development	≤ 20% total site impervious cover; or ≤ 1/3 ac disturbed area
Residential Type III Development	≥ 1,000 SF of additional impervious cover; and > 20% total site impervious cover; or > 1/3 ac disturbed area; or Development within FEMA designated Special Flood Hazard Area

Table 2-2: Non-Residential Development Categories

Category	Criteria
Non-Residential Type I Development	No Variances/Special Use Permits; and No work within easement; and < 400 SF of additional impervious cover
Non-Residential Type II Development	< 1,000 SF of additional impervious cover; and ≤ 30% total impervious cover; or ≤ 1/8 ac disturbed area
Non-Residential Type III Development	> 30% total impervious cover; or > 1/8 ac disturbed area; or Development within FEMA designated Special Flood Hazard Area

If any existing onsite or offsite stormwater infrastructure related to the development is known to be at or above design capacity, the development will be considered a Type III Development.

The submittal and drainage report requirements are outlined below. Submittal requirements are included on the applications available from the City.

2.1.1 PRELIMINARY DRAINAGE PLAN

A Preliminary Drainage Plan of the drainage system is required with preliminary and final plats. A Preliminary Drainage Plan may be required with a zoning, rezoning, special use permit or planned development plan applications. The Preliminary Drainage Plan shall show locations of channels, storm sewers, detention structures, floodplain, floodway, and associated drainage easements at a minimum and shall provide sufficient calculations to verify sizing of facilities.

2.1.2 TYPE I DEVELOPMENT SUBMITTAL

A Type I Development is for use with small-scale residential and non-residential improvements including remodeling, renovations, or minor additions. The submittal shall include all items on a complete application.

2.1.2.1 Type I Drainage Report

A Type I Drainage Report shall be prepared by the property owner or its agent and provide, at a minimum, the following information:

- Applicant contact information (e.g. name, address, phone number, and email address)
- Site location map
- Description of the existing drainage patterns and description of proposed alterations; and
- Temporary erosion control plan

2.1.3 TYPE II DEVELOPMENT SUBMITTAL

A Type II Development is for use with standard residential and small-scale non-residential projects. The submittal shall include all items on a complete application.

2.1.3.1 Type II Drainage Report

A Type II Drainage Report shall be prepared, signed and sealed by a professional engineer licensed in the State of Texas, experienced in civil engineering, and having a thorough knowledge of hydraulic analysis and design.

The report shall contain, at a minimum, the following information:

- Description of the existing drainage patterns and description of proposed alterations;
- Hydrologic calculations for each condition analyzed for the 2-, 10-, 25-, and 100-year storm events; and
- Description and required calculations for hydrologic or hydraulic mitigation.

2.1.4 TYPE III DEVELOPMENT SUBMITTAL

A Type III Development is for use with large-scale residential and standard non-residential improvements. The submittal shall include all items on a complete application and shall be prepared by the agent.

2.1.4.1 Type III Drainage and Water Quality Report

A Type III Drainage and Water Quality Report shall be prepared, signed and sealed by a professional engineer licensed in the State of Texas, experienced in civil engineering, and having a thorough knowledge of hydraulic analysis and design.

The planning and design of drainage systems should ensure that problems are not transferred from one location to another. Grading and other construction activities may not change the terrain in such a way to cause damage to public or private property from drainage or flood problems, increased runoff, or increased erosion or sediment movement.

Existing drainage between developed lots will remain the responsibility of the affected property owners. The developer shall be responsible for the conveyance of all storm drainage flowing through or abutting the subject property, including drainage directed to the property by prior development as well as that naturally flowing by reason of topography. Therefore, drainage computations shall be provided to verify no adverse impact upstream or downstream.

Proposed construction, platting or other development where the proposed activity or change in the land shall not result in post development discharge from the site exceeding discharge under pre-developed conditions (for new development) or existing conditions (for re-development). Downstream capacity shall not be exceeded as a result of development. Additional drainage improvements are not required if drainage improvements have been provided for the fully developed condition, which includes the proposed development.

The report should contain, at a minimum, the following information:

- Description of project location including indication of FEMA defined floodplain zone and Edwards Aquifer zone designation. A copy of the current FEMA floodplain should be provided with the project location indicated;
- Description of the existing drainage patterns and description of proposed alterations;
- Description of all proposed improvements including buildings, roadways, and drainage infrastructure;
- Description and calculation of impervious cover, including a comparison between existing/pre-development and post-development conditions;
- Drainage area maps for all conditions analyzed;
- Hydrologic calculations for all conditions analyzed for the 2-, 10-, 25-, and 100-year storm events;
- Hydraulic calculations for all existing and proposed conveyance systems; and
- Description and calculations for hydrologic or hydraulic mitigation.

2.2 Finished Floor Elevations

Buildings and structures shall have the lowest floor elevated to or above the base flood elevation as prescribed in the City Code Chapter 26. Finished grades shall be sloped to direct stormwater away from the structure. Developments adjacent to stormwater conveyance structures must be elevated above the 100-year water flow elevation (in the conveyance infrastructure) to the same elevation that a development adjacent to a 100-year floodplain would be required to meet.

2.3 Drainage Facility Design

Drainage patterns should be designed to prevent erosion, maintain filtration and recharge of local seeps and springs, and attenuate the harm of contaminants collected and transported by storm water. Overland sheet flow and natural drainage features and patterns shall be maintained to the greatest extent reasonably possible and the dispersion of runoff back to sheet flow shall be the primary objective of drainage design where possible, depending on volumes and velocities of runoff for the development, as opposed to concentrating flows in storm sewers and drainage ditches. The City requires preservation of the natural floodplains. The protection of existing trees and vegetation should be maximized during development of drainage plans.

Where new drainage improvements are required along the boundary of a site, the owner proposing development shall be responsible for designing and constructing all the required improvements at or before the time of development, including the dedication of all ROW or easements necessary to accommodate the improvements. Where the developer proposes to develop only a portion of the property, only the drainage improvements for the portion being developed shall be required to be installed, except as drainage improvements are necessary for proper drainage of the developed portion.

All drainage facilities shall be designed to intercept and transport runoff from a 25-year storm event. The drainage system shall be designed to convey those flows greater than a 25-year storm event, up to and including a 100-year storm event within defined ROW or drainage easements.

Computations to support all drainage designs shall be submitted to the City for review in an easy to follow format. Onsite pre-development stormwater runoff computations shall be based upon conditions representing the existing land conditions with respect to soil type, percentage cover, and cover type as indicated by current aerial imagery and supporting documentation. Design of structures shall use fully developed conditions for the prescribed design storms based on the zoning and/or land use

Modeling and calculations shall be included in drainage report submittals to ensure the specified criteria are met for all drainage infrastructure improvements. Infrastructure that is within TxDOT ROW and requires dual permitting from both the City and TxDOT shall be designed in compliance with the more conservative requirements.

2.3.1 Stream Bank Erosion Hazard Setbacks

Erosion hazard setback determination is necessary for the banks of streams in which the natural channel is to be preserved. The purpose of the setbacks is to reduce the amount of structural damage and stream degradation caused by the erosion of the bank. With the application of stream bank erosion hazard setbacks, an easement is dedicated to the City such that no structure can be located, constructed, or maintained in the area encompassing the erosion hazard setback. Stream bank erosion hazard setbacks are shown in Table 2-3.

The City allows for stream bank stabilization as an alternative to dedicating the erosion hazard setback zone as described in Section 7.4.2.

Table 2-3: Stream Bank Erosion Hazard Setbacks

Contributing Drainage Area (acres)	Setback Distance from Stream Centerline (feet)
0 – 320	0
320 - 640	25
640 or more	50

2.3.2 Temporary Erosion Control

Temporary water quality BMPs shall be required when disturbance could result in erosion that could transport or cause accumulation of sedimentation in dedicated streets, alleys, any waterway, or other private properties during construction activities. Temporary and permanent erosion control requirements are provided in Chapter 7.

2.3.3 Drainage Easements and Right-of-Way

Public drainage easements shall include all natural and manmade drainage ways at least to the limits of the 100-year flood as indicated on the floodplain maps or as determined on the basis of the Drainage and Erosion Control Design Manual and drainage infrastructure necessary to serve public right-of-way. Drainage easements are required for detention and water quality facilities for subdivision and joint detention basins. Easement boundaries shall contain the berms, inlet and outlet structures, access ramps, permanent erosion control facilities, the 100-year water surface, and any additional area needed for access and maintenance. The minimum easement shall be at least 25 feet wide. All drainage easements across private property shall contain the necessary language to permit the required unobstructed water flow, require maintenance of vegetation by the property owner(s), and permit the necessary access by city officials for inspection and repairs.

2.3.4 FREEBOARD

Freeboard is the vertical distance between the design water surface and the elevation of the drainage facility, such as the top of channel, ditch, or detention pond. Freeboard is intended to provide a factor of safety and prevent the fluctuation of the water surface from overflowing the drainage facility. Freeboard requirements are shown in Table 2-4.

Table 2-4: Freeboard Requirements

Drainage Facility	Frequency	Minimum Freeboard
Street ROW	100-year	None
Channels and creek improvements	25-year	0.5 ft
Detention ponds (see note 1)	100-year	1.0 ft
Detention ponds (privately maintained for one single-family lot)	100-year	None
Bridges and culverts	25-year	See note 2

1 Detention ponds maintained by the City, regional detention ponds, or any other detention pond designed for detention of more than one privately maintained single-family lot.

2 Bridge and culverts shall be analyzed to verify any adverse hydraulic impacts are created.

2.4 Stormwater Mitigation

Mitigation through detention, retention, or some other technique must be designed, constructed, and maintained to reduce the post-development peak flow discharge rates to below that of pre-development/existing peak flow discharge rates for the two (2), ten (10), twenty-five (25), and one-hundred (100) year design storms.

Demonstration that no mitigation is in the best interest of the watershed shall be accomplished by showing no adverse impact due to any increased runoff from the proposed development for the design storms. The property owner, or his/her designee, shall meet with the City to discuss impacts and mitigation options prior to commencing the project.

For stormwater mitigation, the following development conditions shall be analyzed with each adverse impact analysis:

A. Pre-Developed Conditions. Refers to the development condition within the watershed prior to any development. This should be used as the baseline for assessing the impact of all new development.
B. Existing Conditions. Refers to current development conditions in the watershed and on site. This shall be used as the baseline for assessing the impact of redevelopment projects.
C. Proposed Conditions. Refers to existing conditions modified with the proposed project development. This shall be used to assess adverse impact to other properties or drainage systems.
D. Post-Developed Conditions. Refers to the proposed condition modified with mitigation. This shall be used to verify the sizing and method of mitigation for the proposed development.
E. Ultimate Conditions. Refers to the development conditions in which all property within the watershed boundaries are developed per maximum zoning requirements.

2.5 Development in the Floodplain

It is the intent of the City Council that the requirements stated in the City Code Chapter 26 comply with federal requirements pertaining to the FEMA authority concerning flood hazards and the USACE jurisdiction over waters of the United States.

No person, individual, partnership, firm, or corporation shall deepen, widen, fill, reclaim, reroute or change the course or location of any existing ditch, channel, stream or drainage way without first obtaining a permit from the City and any other applicable agencies having jurisdiction, such as FEMA or the USACE. The City may require preparation and submission of a FEMA study for a proposed development if there are concerns regarding storm drainage on the subject property or upstream or downstream from the subject property. The costs of such study, application, and/or permit, if required, shall be borne by the developer.

2.6 Permanent Water Quality Controls

Development and redevelopment located over the Edwards Aquifer regulatory zones shall comply with the latest TCEQ published rules and technical design guidance for the Edwards Aquifer in accordance with 30 TAC Chapter 213 (Edwards Aquifer Rules). Permanent water quality BMPs for development outside of the Edwards Aquifer regulated zones shall be designed to provide adequate treatment of the water quality volume in the City's jurisdiction as defined in Chapter 6.

2.7 Maintenance of Drainage Facilities

All drainage facilities located in the street ROW except driveway culverts, shall be maintained by the appropriate jurisdiction. The property owner shall maintain all drainage facilities located on private property including driveway culverts. Authorized inspectors of the City shall have the right of entry on the land or premises where property owners are required to maintain drainage facilities or detention facilities, at reasonable times and after notifying the property owner, for the purpose of inspection of the maintenance.

2.7.1 Maintenance Access

Access shall be provided to all ponds and channel maintained by the City, regional drainage facilities, or any other drainage facility designed for drainage of more than one privately maintained single-family lot as follows: ponds and channels shall provide a maintenance access with a width of at least 12 feet and have a vertical grade no steeper than 6H:1V. Access shall be provided within dedicated ROW or within the drainage easement and shall be clearly identified on plans.

Maintenance schedules and descriptions of maintenance practices for privately maintained single-family residential ponds and channels shall be provided within the plans or as a separate document. Adequate access shall be provided for the maintenance description provided.

CHAPTER 3 DETERMINATION OF STORM RUNOFF

3.1 General Requirements

The selection of the appropriate method for calculating runoff depends upon the size of the drainage area, time of concentration, and detention mitigation. Flows are to be analyzed for both existing and proposed conditions at all locations where runoff leaves a proposed project for the 2-, 10-, 25-, and 100- year frequencies. Design discharges are to be calculated by either the Rational Method or the NRCS Unit Hydrograph Method.

The Rational Method is accepted as adequate for drainage areas totaling 200 acres or less with no detention or timing considerations. The National Resources Conservation Service hydrologic methods should be used for drainage areas larger than 200 acres but may also be used for drainage areas of any size. The method of analysis must remain consistent when drainage areas are combined and the method that applies to the largest combined drainage area should be used.

3.2 Design Rainfall

Rainfall, along with watershed characteristics, determines the storm runoff flows upon which storm drainage design is based.

3.2.1 RAINFALL INTENSITY DURATION FREQUENCY

Intensity-Duration-Frequency curves provide a summary of a site's rainfall characteristics by relating storm duration and storm frequency to rainfall intensity. The Intensity-Duration-Frequency curve parameters, included in Table 3-1, from the City of Austin DCM shall be used.

Table 3-1: Intensity Duration Frequency Parameters

Return Period	a	b	c
2	45.24	9.339	0.7399
10	61.25	8.352	0.7147
25	69.96	7.941	0.6954
100	77.31	6.832	.6524
500	77.48	4.967	0.5837

3.2.1 RAINFALL DEPTH DURATION FREQUENCY

The appropriate rainfall depths for calculations in the City are provided in Table 3-2. These are estimated from analysis performed for rainfall data available in the State of Texas. [1]

Table 3-2: Depth-Duration-Frequency (inches)

Duration	Return Period				
	2-year	10-year	25-year	100-year	500-year
5 min	0.53	0.80	0.98	1.28	1.68
15 min	1.06	1.60	1.96	2.54	3.34
30 min	1.49	2.25	2.75	3.54	4.69
1 hr	1.96	2.99	3.66	4.77	6.45
2 hr	2.42	3.82	4.81	6.57	9.27
3 hr	2.70	4.34	5.55	7.81	11.31
6 hr	3.17	5.21	6.78	9.79	14.48
12 hr	3.64	6.02	7.85	11.37	16.94
24 hr	4.14	6.84	8.90	12.80	19.05

3.3 The Rational Method

The Rational Method is appropriate for estimating peak discharge in basins that do not require detention or timing considerations. The method is based on the direct relationship between rainfall and runoff and is given by the following relationship (Equation 3-1):

$$Q=k(ciA) \qquad \text{(Equation 3-1)}$$

Where:

Q = peak runoff (cfs)
k = Antecedent Precipitation Coefficient (Table 3-3)
c = Runoff Coefficient (Table 3-4)
i = Average rainfall intensity (in/hr)
A= Drainage area (ac)

Table 3-3: Antecedent Precipitation Coefficient (k)

Frequency	k
2 year	1.00
10 year	1.00
25 year	1.10
100 year	1.25

The Rational Method equation is based on the following assumptions:

- Rainfall intensity is constant over the time it takes to drain the watershed (time of concentration)
- The runoff coefficient remains constant during the time of concentration
- The watershed area does not change
- The minimum time of concentration is not less than 10 minutes and does not exceed 3-hours

3.3.1 Runoff Coefficient

Suggested runoff coefficients (c) with respect to specific surface types are given in Table 3-4. The runoff coefficients include an antecedent precipitation factor to reflect the additional runoff that results from saturated ground conditions with less frequent recurrence intervals. The City must approve assumptions for fully developed conditions where maximum allowable impervious cover is not defined by City Code. Runoff coefficients for developed conditions should be based on composite values given by Equation 3-2.

$$\mathrm{c} = \mathrm{I}\mathrm{c}_\mathrm{i} + (1 - \mathrm{I})c_\mathrm{p} \qquad \text{(Equation 3-2)}$$

Where:

c = Composite runoff coefficient
I = Impervious cover (%)
c_i = Runoff coefficient for impervious cover
c_p = Runoff coefficient for pervious cover

Table 3-4: Runoff Coefficient (c)

Surface (Developed)			**c**	**Area (Undeveloped)**	**c**
Pavement				Cultivated	
Asphaltic			0.81	Flat, 0-2%	0.36
Concrete			0.83	Average, 2-7%	0.41
Grass (Lawn, Parks)				Steep, over 7%	0.44
Condition	Poor	Fair	Good	Pasture/Range	
Flat, 0-2%	0.37	0.30	0.25	Flat, 0-2%	0.30
Average, 2-7%	0.43	0.38	0.35	Average, 2-7%	0.38
Steep, over 7%	0.45	0.42	0.40	Steep, over 7%	0.42
"Poor" consists of less than 50 percent coverage. "Fair" consists of between 50 and 75 percent coverage. "Good" consists of greater than 75 percent coverage.				Forest/Woodlands	
				Flat, 0-2%	0.28
				Average, 2-7%	0.36
				Steep, over 7%	0.41

3.3.2 Time of Concentration

The time of concentration is the time for surface runoff to flow from the most hydraulically remote point in the drainage basin to the drainage point of interest. The most hydraulically remote point refers to the route requiring the longest drainage travel time and not necessarily the greatest linear distance. Furthermore, the most hydraulically remote point must be taken from a location that best represents the majority of the contributing area.

The preferred procedure for estimating time of concentration is the Natural Resources Conservation Services (NRCS) method as described in Technical Release 55 [2]. This method is outlined below. The time of concentration to any point in a storm drainage system is the sum of the sheet flow (overland), the shallow concentrated flow, and the channel flow, which may include storm drains. Note that there may be multiple shallow concentrated and channel segments depending on the nature of the flow path. The minimum time of concentration for any drainage area shall be 10 minutes.

Sheet Flow

Sheet flow is shallow flow over land surfaces, which usually occurs in the headwaters of streams. The engineer should realize that sheet flow occurs for only very short distances, especially in urbanized conditions. Sheet flow for both natural (undeveloped) and developed conditions should be limited to a maximum of 100 feet. Sheet flow for developed conditions should be based on the actual pavement or grass conditions for areas that are already developed and should be representative of the anticipated land use within the headwater area in the case of currently undeveloped areas. In a typical residential subdivision, sheet flow may be the distance from one end of the lot to the other or from the house to the edge of the lot. In some heavily urbanized drainage areas, sheet flow may not exist in the headwater area. The NRCS method employs Equation 3-3, which is a modified form kinematic wave equation, for the calculation of the sheet flow travel time.

$$T_t = \frac{0.42(nL)^{0.8}}{P_2^{0.5} s^{0.4}} \qquad \text{(Equation 3-2)}$$

Where:

T_t = Travel time (min)
L = Length of the reach (ft)
n = Manning's coefficient (Table 3-5)
P_2 = 2-year, 24-hour rainfall (in) (Table 3-2)
s = Slope of the ground (ft/ft)

Overland flow

After a maximum of approximately 100 feet, sheet flow usually becomes shallow concentrated flow collecting in swales, small rills, and gullies. Shallow concentrated flow is assumed not to have a well-defined channel and has flow depths of 0.1 to 0.5 feet. The travel time for shallow concentrated flow can be computed by Equation 3-4.

$$T_t = \frac{Ln}{(60s^{0.5})} \qquad \text{(Equation 3-3)}$$

Where:

T_t = Travel time (min)
L = Length of the reach (ft)
n = Manning's coefficient (Table 3-5)
s = Slope of the ground (ft/ft)

Table 3-5: Manning's Coefficients for Overland Flow

Surface Description	Manning's Coefficient (n)
Concrete (rough or smoothed finish)	0.015
Asphalt	0.016
Fallow (no residue)	0.050
Cultivated Soils:	
Residue Cover ≤ 20%	0.060
Residue Cover > 20%	0.170
Grass:	
Short-grass prairie	0.150
Dense grasses	0.240
Bermuda Grass	0.410
Range (natural)	0.130
Woods:	
Light Underbrush	0.400
Dense Underbrush	0.800
Source: City of Austin Drainage Criteria Manual [3]	

Channel flow

The velocity in an open channel or a storm drain not flowing full can be determined by using Manning's Equation. Channel velocities can also be determined by using backwater profiles. For open channel flow, average flow velocity is usually determined by assuming a bank-full condition. The channel flow component of the time of concentration may need to be divided into multiple segments in order to represent significant changes in channel characteristics. The details of using Manning's Equation and selecting Manning's coefficient for channels can be obtained from HEC-22. Manning's coefficients for channel flow are located in Table 4-3. For conveyance within storm drains, Manning's coefficients are included in Table 3-6.

Table 3-6: Manning's Coefficients for Closed Conduits

Material	Manning's Coefficient (n)
Asbestos-cement pipe	0.011-0.015
Concrete pipe	0.011-0.015
Concrete box	0.012-0.015
Corrugated metal pipe	0.018-0.026
Polyvinyl chloride (PVC) pipe	0.009-0.011
Source: TxDOT Hydraulic Design Manual [4]	

3.3.3 Rainfall Intensity

Rainfall intensity (i) is the average rainfall rate in inches per hour, and is selected based on design rainfall duration and design frequency of occurrence. The design duration is equal to the time of concentration for the drainage area under consideration. The design frequency of occurrence is a statistical variable that is established by design standards or chosen by the engineer as a design parameter.

The rainfall intensity used in the rational method can be calculated the value of rainfall intensity from the parameters, Table 3-1, and Equation 3-6 with the known Tc value for the entire drainage area.

$$i = \frac{a}{(T_c + b)^c} \qquad \text{(Equation 3-6)}$$

3.4 NRCS Unit Hydrograph

The preferred unit hydrograph in general is the NRCS Dimensionless Unit Hydrograph. The runoff curve number used in calculating the existing/pre-development condition and the post-development condition shall be documented. A fully developed drainage area shall be assumed for the post-development condition. Average antecedent moisture conditions II (AMC II) shall be assumed.

3.4.1 Curve Number

Rainfall infiltration losses depend primarily on soil characteristics and land use (surface cover). The NRCS method uses a combination of soil conditions and land use to assign runoff Curve Numbers. NRCS curve numbers are to be selected from Table 3-7. Note that Curve Numbers are whole numbers. For a watershed that has variability in land cover and soil type, a composite Curve Number is calculated and weighted by area.

Table 3-7: Runoff Curve Numbers

Cover Description	Curve Numbers for Hydrologic Soil Group			
	A	B	C	D
Developed Areas				
Streets and Roads	98	98	98	98
Commercial and business (85% IC)	89	92	94	95
Residential: 1/8 acre or less (65% IC)	77	85	90	92
Residential: 1/4 acre (38% IC)	61	75	83	87
Residential: 1/3 acre (30% IC)	57	72	81	86
Residential: 1/2 acre (25% IC)	54	70	80	85
Residential: 1 acre (20% IC)	51	68	79	84
Residential: 2 acre (12% IC)	46	65	77	82
Open Space: Poor Condition	68	79	86	89
Open Space: Fair Condition	49	69	79	84
Open Space: Good Condition	39	61	74	80
Undeveloped Areas				
Pasture, grass land or range: Poor Condition	68	79	86	89
Pasture, grass land or range: Fair Condition	49	69	79	84
Pasture, grass land or range: Good Condition	39	61	74	80
Meadow – continuous grass	30	58	71	78
Brush: Poor Condition	48	67	77	83
Brush: Fair Condition	35	56	70	77
Brush: Good Condition	30	48	65	73
Woods-grass combination: Poor Condition	57	73	82	86
Woods-grass combination: Fair Condition	43	65	76	82
Woods-grass combination: Good Condition	32	58	72	79
Woods: Poor Condition	45	66	77	83
Woods: Fair Condition	36	60	73	79
Woods: Good Condition	30	55	70	77
"Poor" consists of less than 50 percent coverage. "Fair" consists of between 50 and 75 percent coverage. "Good" consists of greater than 75 percent coverage.				

Curve numbers can be reduced by either using a climatic adjustment as described in the 2016 TxDOT Hydraulic Design Manual (HDM) [4] or calibrating to historical storms. If curve numbers are calibrated from historical storms, the Engineer must provide documented data for rainfall, stream flow data, or detention pond stage storage data used to determine the historical curve numbers.

3.4.1 LAG TIME

Time of concentration shall be computed using the same techniques as for the Rational Method. The lag time, defined as the time between the center of mass of excess rainfall to the runoff peak, is typically used in the Hydrologic Modeling System (HEC-HMS) implementation of the NRCS methodology. The lag time can be estimated with Equation 3-7.

$$T_l = 0.6T_c \qquad \text{(Equation 3-7)}$$

The NRCS Unit Hydrograph shall be analyzed using 24-hour rainfall depths provided in Table 3-2. The 24-hour rainfall depths are to be distributed temporally with the NRCS Type III rainfall distribution.

CHAPTER 4 DESIGN OF DRAINAGE INFRASTRUCTURE

4.1 General Requirements

The following sections apply to the design of improvements within existing or proposed public ROW to minimize the interference to traffic and the likelihood of stormwater damage to surrounding property.

4.2 Street Flow

Interference to traffic is regulated by design limits of the spread of water into traffic lanes. Runoff shall not enter private property from a street except in recorded drainage easements or ROW, or in historic watercourses where easements or ROW have not been obtained.

Driveways should be constructed to allow the runoff from a 25-year design storm to pass under the driveway in a culvert (18 inches minimum or equivalent) or over the driveway on a concrete apron where conveyance is parallel to the roadway. Concrete aprons or box culverts are preferred in areas of heavy sediment transport.

The side slope of a ditch or swale on the side adjacent to City roads shall be no steeper than 4H:1V. Roadways under TxDOT jurisdiction shall be designed in accordance with TxDOT requirements.

4.2.1 Flow at Intersections

As the stormwater flow approaches a street or tee intersection, an inlet is required. The inlet cannot be placed inside the curb return. Valley gutters can be useful in diminishing the deterioration of pavements, particularly at intersections where flows tend to concentrate. At the intersection of two (2) thoroughfare or arterial streets, a valley gutter cannot be used. At the intersection of two (2) collector streets or local streets, the valley gutter may be used. At an intersection of two (2) different types of streets, a valley gutter may be used across the smaller street only.

4.2.2 Permissible Spread of Water

The flow of water in gutters of typical streets during the 25-year storm shall be contained below the top of curb and shall maintain the clear width requirements listed in Table 4-1. The flow of water shall be limited to a maximum of 6-inches above the top of crown during the 100-year storm event and must be contained within the defined ROW and easements. These clear widths at the crown of the roadway or at the high point on a divided roadway are necessary to provide access for vehicles in the event of an emergency.

Table 4-1: Water Spread Limits for Roadways

Street Classification	25-year permissible water spread
Thoroughfare	All lanes must remain open
Arterial Street	One 11-foot traffic lane must remain open in each direction
Collector Streets	Clear width of 11-feet must remain open
Minor Streets	Maximum depth of 6-inches

4.2.3 Street Flow Calculations

Evaluation of street flow is based upon open channel hydraulics theory, with the Manning's Equation modified to allow direct solution, based on the street cross section. The methodology included in the *Hydraulic Engineering Circular 22: Urban Drainage Design Manual (HEC 22)* [5] should be followed for determining proposed roadway improvements.

4.3 Inlet Design

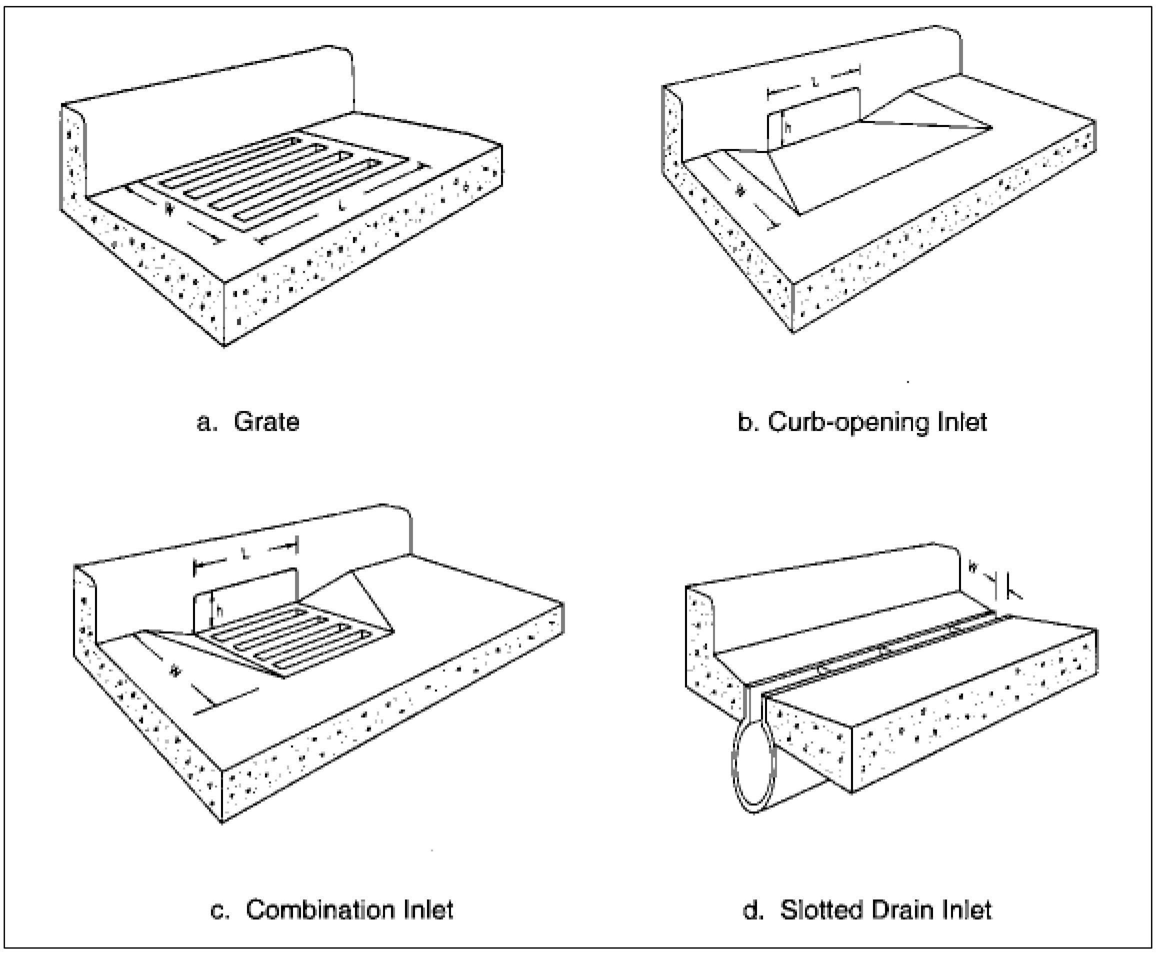
Inlets shall be located as necessary to remove the flow based on the 25-year storm and accommodate ponding widths in streets as defined in Table 4-1. The hydraulic efficiency of storm drain inlets varies with the amount of gutter flow, street grade, street crown, and the geometry of the inlet opening. No lowering of the standard height of street crown shall be allowed for the purposes of obtaining additional hydraulic capacity.

4.3.1 Inlet Types and Descriptions

Storm drain inlets are designed to collect and convey runoff to a storm drainage system. They are typically located at the street curb, paved medians, and in roadside and median ditches. The inlets are commonly divided into four categories:

a. Grate inlets
b. Curb-opening inlets
c. Combination inlets
d. Slotted drain inlets

Figure 4-1: Types of Storm Drainage Inlets



Source: HEC 22

4.3.1.1 Grate Inlets

Grate inlets are installed in the area of the roadway where the water is flowing and perform reasonably over a wide range of gutter grades. Some of the disadvantages are they lose capacity with increase in grade, may clog by debris, and pose a hazard to bicycle and wheelchair traffic. Therefore, these inlets must be configured to be safe for wheelchairs and bicycles.

4.3.1.2 Curb-Opening Inlets

Curb-opening inlets function effectively on flatter slopes or sags and where there is potential for a significant amount of debris in the gutter flow. They lose interception capacity as the gutter grade increases and therefore are recommended to be placed in grades no steeper than 3%.

4.3.1.3 Combination Inlets

Combination inlets have a high runoff interception capacity as they incorporate both the grate inlet and the curb opening inlet. If the curb opening is placed upstream of the grate inlet, it will act as a “sweeper” by intercepting floating debris in the early phase of a storm.

4.3.1.4 Slotted Drain Inlets

Linear inlets, slotted drains and trench drains, are placed in areas where runoff needs be intercepted over a wide section with low flows. The main disadvantage is they are very vulnerable to clogging from sediments and debris. Slotted drains may only be used with City permission. Trench drains are acceptable for use on driveways and low volume areas.

4.3.2 Inlet Capacity Calculations

The inlet capacity calculations shall be performed using the methodology contained in the TxDOT HDM.

4.3.2.1 Inlets On-Grade

The interception capacity of inlets on grade is dependent on the cross slope, longitudinal slope, total gutter flow, and pavement. The interception capacity of all inlet configurations increases with increasing flow rates, and inlet efficiency generally decreases with increasing flow rates. Designs must account for bypass flow.

4.3.2.2 Inlets in Sag Configurations

Inlets in a sag locations operate as weirs under low head conditions and as orifices at greater depths. Orifice flow begins at depths dependent on the grate size, the curb opening height, or the slot width of the inlet. At depths between those at which weir flow prevails and those at which orifice flow prevails, flow is in a transition stage. At these depths, control is ill defined and flow may fluctuate between weir and orifice control.

The efficiency of inlets in passing debris is critical in sag locations because all runoff which enters the sag must be passed through the inlet. Total or partial clogging of inlets in these locations can result in hazardous ponded conditions. Grate inlets alone are not recommended for use in sag locations because of the tendencies of grates to become clogged. Combination inlets or curb opening inlets are recommended for use in these locations.

4.4 Storm Drain Systems

The combined street system, including ditches, swales, and channels, directs flow into a collection structure, such as an inlet or grate, and deposits flow into the storm drain system. The objective is to provide safe passage of vehicle traffic by collecting stormwater from roadway surfaces and safely conveying it to an adequate receiving body.

4.4.1 GENERAL REQUIREMENTS

The following shall be considered during the design of storm drain systems.

a. Storm drain pipe shall be reinforced concrete pipe (AASHTO M170 Class III). Corrugated metal pipe or plastic pipe shall not be permitted for storm drain systems in the public ROW.
b. Manholes or junction boxes must be used at all pipe size changes on trunk lines. For all pipe junctions, other than manholes and junction boxes, manufactured wye connections should be used, and the angle of intersection shall not be greater than 45 degrees. Laterals shall be connected to trunk lines using manholes or manufactured wye connections. Vertical curves in the conduit will not be permitted, and horizontal curves must meet manufacturer's requirements for offsetting of the joints.
c. The maximum manhole and junction box spacing for storm drain systems are shown in Table 4-2. Manholes or junction boxes shall also be placed at pick up points having three or more laterals; vertical alignment changes; and future collection points. The requirement for manholes may be waived if the pipe size allows direct access into the pipe by maintenance personnel and equipment.
d. The cover over the crown of circular pipe should be at least three feet and should be based on the type of pipe used, the expected loads, and the supporting strength of the pipe. Box sections should normally have a minimum of one foot of cover; however, box sections may be designed for direct traffic in special situations with approval.
e. Grates for drop inlets should be designed to facilitate removal for maintenance, but minimize vandalism. Design shall consider traffic loading, bicycle and pedestrian safety, and a means to secure the grate.
f. At no time shall bypass flow exceed the water spread limits for roadways as defined by Table 4-1. Inlets shall be located to prevent water convergence and/or excessive flows through intersections.
g. For arterial or collector streets with super-elevated sections, no more than 3 cubic feet per second of the 25-year flow will be allowed to cross from the higher elevation to the lower elevation.

Table 4-2: Maximum Manhole Spacing

Pipe Diameter (in)	Max. Spacing (ft)
24	400
27-39	800
42-60	1,000
Larger than 60	1,200

4.4.2 DESIGN CRITERIA

The capacity of a storm drain network has several limiting factors, including the total incoming flow dependent on the severity of the storm, size, shape, and material of the network pipes, flow rate, and velocity, geometric changes causing energy losses, and exiting structure. To design a storm drain system, the following criteria will be used to create a system with the necessary capacity.

a. The design storm shall be the 25-year storm with provisions made for the 100-year storm. Design of storm drain systems shall follow the TxDOT HDM, utilizing Manning’s Equation for closed conduits and step backwater methodology for open channels. For Manning’s equation, the minimum roughness coefficient for a concrete storm pipe is 0.013.
b. Conduits within the storm drain system shall have a minimum velocity of 2 feet per second. This requirement shall protect the ability of the system to convey the design storm by limiting or preventing the accumulation of sediment within closed conduits.

c. Maximum conduit velocities for trunk lines and inlet laterals longer than 30 feet are 12 feet per second. A maximum velocity is required to prevent the erosion of the storm pipe material over time. The exiting velocity of a given storm drain system must be below the design velocity for the receiving channel or outfall structure. Erosion control measures are required for all outfalls into natural channels.
d. All energy losses, including entrance and exit losses, expansion losses, manhole and bend losses, junction losses, and minor head losses at points of turbulence, shall be included in calculations to determine the hydraulic gradient.
e. Storm lines discharging into open channels shall have flowlines higher or equal to those of the receiving open channel. The storm system is not allowed to be at sump with the channel.
f. Slope, along with larger diameter pipes located downstream, must be utilized such that the velocity of flow features a gradual increase, or at a minimum prevent large decreases at changes in geometry, including bends and inlets, to prevent sedimentation from occurring.
g. At connections of pipes with differing diameters, the pipe crowns (soffits) shall be matched, instead of matching the flow lines.

4.4.3 Calculation of the Hydraulic Grade Line

The hydraulic grade line (HGL) for a conduit system must be calculated with the inclusion of all energy losses and depicted in the system profile drawing. The hydraulic grade line must be computed and drawn for both the 25-year design storm and the 100-year storm. The methodology for calculating the hydraulic grade line is located in HEC 22.

4.4.3.1 Tailwater Conditions

The capacity of a system is dependent on the tailwater conditions, thus the tailwater conditions must be determined prior to designing storm drain systems. When calculating the hydraulic performance of a storm drain system discharging into an existing watercourse, tailwater elevation must be determined by the design engineer. However, the tailwater elevation must be greater than the existing water surface of the receiving channel and the minimum outlet water surface.

The design engineer must also determine the maximum outlet velocities of the storm drain network and include the "Normal Depth" outfall analysis. As a part of the analysis, the design engineer must solve the downstream boundary condition using Manning's equation for Normal Depth.

4.4.3.2 Head Loss

To design a conduit system, the head loss within the system must be computed. The head loss is the combined friction losses, minor losses, and junction losses for the system. The procedure for calculating head loss is included in the TxDOT HDM.

4.5 Open Channels

The general classifications for open channels are natural channels, which include all watercourses that have been carved by nature through erosion; and engineered channels, which are constructed or existing channels that have been significantly altered by human effort. No person shall place or cause to be placed any obstruction of any kind in any watercourse within the City and its ETJ. The owner of any property within the City, through which any watercourse may pass, shall keep the watercourse free from obstruction.

4.5.1 Design Criteria

The parameters that need to be considered in channel design include: flow capacity, permissible velocity, side slope, and freeboard.

- Flow Capacity: All channels shall be designed to convey the 100-year storm event with freeboard in accordance with Table 2-4;
- Permissible Velocity: The minimum permissible velocity is 2 fps for the 25-year storm. The maximum permissible velocity for the 100-year storm must be non-erosive; and
- Side Slopes: The channel slopes shall be 3H:1V or flatter.

4.5.2 ROUGHNESS COEFFICIENTS

The roughness coefficients describe the degree of resistance that natural or artificial channels have to flow conveyance. The recommended roughness coefficient values for use in open channel hydraulic analyses are presented in Table 4-3.

Table 4-3: Roughness Coefficients

Type of Channel and Description	Minimum	Normal	Maximum
LINED OR BUILT-UP CHANNELS			
Concrete-lined	0.012		0.025
Concrete rubble	0.017		0.030
UNLINED CHANNELS			
Earth, straight, and uniform	0.017		0.025
Winding and sluggish	0.022		0.030
Rocky beds, weeds on bank	0.025		0.040
Earth bottom, rubble sides	0.028		0.035
Rock cuts	0.025		0.045
NATURAL STREAMS			
Minor Streams (top width at flood stage<100 ft)			
Streams on plain			
clean, straight, full stage, no rifts or deep pools	0.025	0.030	0.033
clean and straight with more stones and weeds	0.030	0.035	0.040
clean, winding, some pools and shoals	0.033	0.040	0.045
clean and winding but some weeds and stones	0.035	0.045	0.050
same as above, lower stages, more ineffective slopes and sections	0.040	0.048	0.055
clean, winding, some pools and shoals with more stones	0.045	0.050	0.060
sluggish reaches, weedy, deep pools	0.050	0.070	0.080
very weedy reaches or floodways with heavy underbrush	0.075	0.100	0.150
Floodplains			
Pasture, no brush			
short grass	0.025	0.030	0.035
high grass	0.030	0.035	0.050
Brush			
scattered brush, heavy weeds	0.035	0.050	0.070
light brush and trees, in winter	0.035	0.050	0.060
light brush and trees, in summer	0.040	0.060	0.080
medium to dense brush, in winter	0.045	0.070	0.110
medium to dense brush, in summer	0.070	0.100	0.160
Trees			
dense willows, summer, straight	0.110	0.150	0.200
cleared land with tree stumps, no sprouts	0.030	0.040	0.050
cleared land with tree stumps with heavy growth of sprouts	0.050	0.060	0.080

Type of Channel and Description	Minimum	Normal	Maximum
heavy stand of timber and little undergrowth	0.080	0.100	0.120
same as above with flood stage reaching branches	0.100	0.120	0.160
Major Streams (top width at flood stage>100 ft)			
Regular section with no boulders or brush	0.025		0.060
Irregular and rough section	0.035		0.100

4.5.3 CHANNEL ANALYSIS

For the analysis and design of open channels the depth and velocity of flow are necessary. For the hydraulic analysis of open channels, the following two methods are commonly used:

- Slope Conveyance Method
- Standard Step Backwater Method

The above two methods of analysis are included in the TxDOT Hydraulic Design Manual.

4.5.4 SUPERCRITICAL FLOW

The Froude Number, Equation 4-1, provides a relationship between flow velocity and the hydraulic depth of flow, and gravitational action and shall be calculated for all channel improvement designs. Subcritical flow conditions occur when the Froude Number is less than 1.0 and supercritical flow conditions exist in lined channels when the Froude Number exceeds 1.0.

If the normal depth in a channel is supercritical, its alternate depth is a deeper subcritical depth. Obstructions that may enter a stream during a storm event may cause supercritical flows to experience a hydraulic jump and become subcritical flows. When it is calculated that supercritical conditions could occur for the design storm, the depth of the channel must be at least the alternate depth plus the required freeboard. Adequate protection of the channel must be provided to protect against supercritical flow.

Subcritical flow conditions are recommended for all channel designs, as supercritical flow tends to have high velocities and high potential for channel erosion. Supercritical flow conditions will not be allowed in channels with a vegetative lining. Subcritical flow conditions may be achieved by using energy dissipators in areas where the existing topography will not allow subcritical flow conditions to occur naturally. In all cases, the channel improvements shall be designed to avoid the unstable transitional flow conditions that occur when the Froude Number is between 0.9 and 1.1.

$$F = \frac{v}{\sqrt{gD}} \qquad \text{Equation 4-1}$$

Where:

F=Froude number (dimensionless)
v=average velocity (ft/s)
g=gravitational acceleration (32.3 ft/s^2)
D=hydraulic depth (ft)

4.5.5 SHEAR STRESS

Shear stress represents the component of stress that acts in the direction of the flow. Shear stress shall be computed for all open channels and adequate protection shall be provided based on the tractive force method described in HEC 15 [6] and the permissible shear stresses reported in the TxDOT HDM.

The shear stress at normal depth should be computed. The channel lining selected, Table 4-4, will determine the permissible shear stress, Table 4-5. If the computed shear stress is less than the permissible stress, the lining is adequate. Otherwise, consider the following options: choose a more resistant lining, decrease channel slope, decrease slope in combination with drop structures, or increase channel width or flatten side slopes. Non-native plants are prohibited for use within channels.

Table 4-4: Retardation Class for Lining Materials

Retardance Class	Cover	Condition
A	Weeping lovegrass	Excellent stand, tall (average 30 in. or 760 mm)
B	Native grass mixture little bluestem, bluestem, blue gamma, other short and long stem midwest grasses	Good stand, uncut
	Weeping lovegrass	Good Stand, tall (average 24 in. or 610 mm)
	Lespedeza sericea	Good stand, not woody, tall (average 19 in. or 480 mm)
	Alfalfa	Good stand, uncut (average 11 in or 280 mm)
	Weeping lovegrass	Good stand, uncut (average 13 in. or 330 mm)
	Blue gamma	Good stand, uncut (average 13 in. or 330 mm)
C	Crabgrass	Fair stand, uncut (10-to-48 in. or 55-to-1220 mm)
	Bermuda grass	Good stand, mowed (average 6 in. or 150 mm)
	Common lespedeza	Good stand, uncut (average 11 in. or 280 mm)
	Grass-legume mixture: summer (orchard grass redtop, Italian ryegrass, and common lespedeza)	Good stand, uncut (6-8 in. or 150-200 mm)
	Centipedegrass	Very dense cover (average 6 in. or 150 mm)
	Kentucky bluegrass	Good stand, headed (6-12 in. or 150-305 mm)
D	Bermuda grass	Good stand, cut to 2.5 in. or 65 mm
	Common lespedeza	Excellent stand, uncut (average 4.5 in. or 115 mm)
	Buffalo grass	Good stand, uncut (3-6 in. or 75-150 mm)
	Grass-legume mixture: fall, spring (orchard grass Italian ryegrass, and common lespedeza	Good Stand, uncut (4-5 in. or 100-125 mm)
	Lespedeza sericea	After cutting to 2 in. or 50 mm (very good before cutting)
E	Bermuda grass	Good stand, cut to 1.5 in. or 40 mm
	Bermuda grass	Burned stubble
Source: TxDOT HDM		

Table 4-5: Permissible Shear Stress for various linings

Protective Cover	(lb/sf)
Retardance Class A Vegetation	3.70
Retardance Class B Vegetation	2.10
Retardance Class C Vegetation	1.00
Retardance Class D Vegetation	0.60
Retardance Class E Vegetation	0.35
Woven Paper	0.15
Jute Net	0.45
Single Fiberglass	0.60
Double Fiberglass	0.85
Straw W/Net	1.45
Curled Wood Mat	1.55
Synthetic Mat	2.00
Gravel, D50 = 1 in. or 25 mm	0.40
Gravel, D50 = 2 in. or 50 mm	0.80
Rock, D50 = 6 in. or 150 mm	2.50
Rock, D50 = 12 in. or 300 mm	5.00
6-in. or 50-mm Gabions	35.00
4-in. or 100-mm Geoweb	10.00
Soil Cement (8% cement)	>45
Dycel w/out Grass	>7
Petraflex w/out Grass	>32
Armorflex w/out Grass	12-20
Erikamat w/3-in or 75-mm Asphalt	13-16
Erikamat w/1-in. or 25 mm Asphalt	<5
Armorflex Class 30 with longitudinal and lateral	>34
Dycel 100, longitudinal cables, cells filled with mortar	<12
Concrete construction blocks, granular filter	>20
Wedge-shaped blocks with drainage slot	>25
Source: TxDOT HDM	

4.5.6 Energy Dissipators

Energy dissipators are commonly used for culverts and channels in order to prevent erosion problems by dissipating the flow energy at specific locations prior to discharging downstream. Design methodology for these structures is presented in HEC-14 [7].

The energy dissipators fall under different categories including:

- Internal Dissipators
- Stilling Basins
- Streambed Level Dissipators
- Riprap Basins and Aprons
- Drop Structures
- Stilling Wells

4.6 Bridges and Culverts

A bridge is defined as a structure, including supports, erected over a depression or having a roadway for carrying traffic or other moving loads, and having an opening measured along the center of the roadway of more than 20 feet between faces of abutments, spring lines of arches, or extreme ends of openings for multiple box culverts. Culverts convey surface water through a roadway embankment away from the roadway ROW or into a channel along the ROW.

4.6.1 General Requirements

All proposed bridges and culverts must meet the following criteria:

a. All culverts shall be a minimum size of a 18-inch circular pipe or equivalent for alternate shapes. Reinforced concrete shall be the material of choice. Other materials must be approved by the City.
b. Allowance shall be made for conveyance of the 100-year runoff across the road and into the downstream channel without damage to the road or adjacent property.
c. Temporary crossings shall be designed to safely pass the 2-year design storm runoff.
d. The backwater created by a culvert or bridge during the 100-year design storm runoff shall not cause damage to public or private property.
e. Culvert outlets shall be designed to minimize damage caused by erosion.
f. Culverts and bridges shall be aligned with natural drainage ways in grade and direction whenever practical. Culverts shall have a minimum design storm velocity of 2.5 feet per second to reduce sediment accumulation.
g. Larger culvert sizes, bridges, box culverts, and/or smooth-walled pipes are recommended for crossings where heavy debris or sediment accumulations are anticipated. Trash racks may be required.
h. All headwalls shall be constructed of reinforced concrete.

4.6.2 Bridge Design Criteria

Additional design criteria from that stated above will be on a case-by case basis as determined by the City Engineer.

4.6.3 Culvert Design Criteria

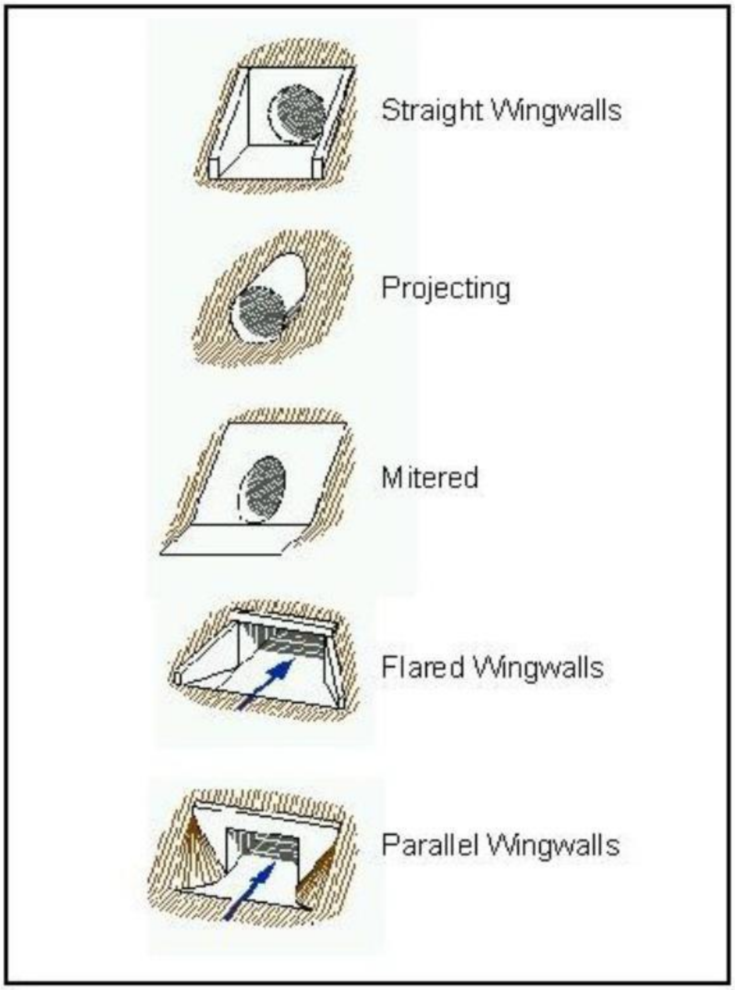
All proposed culverts shall be designed to meet the following criteria:

a. Headwalls and necessary erosion protection shall be provided at all culverts and shall comply with TxDOT standard details. All culverts and bridges are to be analyzed at both the design flow and 100-year check flow.
b. Alignment, location, and grade of proposed culverts must be consistent with planned development of the drainage system for that watershed. In the event the particular watershed or waterway is not covered by a planned storm drainage system, the designer should proceed with the design from the nearest downstream control and design the proposed drainage system improvements anticipating future system expansion due to fully developed watershed conditions.
c. Wingwalls, if used, may be either straight parallel, flared, or tapered. Approach and discharge aprons shall be provided for all culvert headwall designs. Precast headwalls and end walls may be used if all other criteria are satisfied.

4.6.4 CULVERT END TREATMENTS

End Treatment of a culvert is to create safer conditions surrounding the culvert without interfering with the hydraulics of the culvert design. There are a multitude of end treatments available for culverts. The TxDOT Bridge Division maintains standard details of culvert end treatments. Typical end treatments are depicted in Figure 4-2. Safety end treatments (SET), such as those used with driveway and other small diameter culverts, may be more hydraulically efficient by providing both tapered wingwalls and a beveled edge instead of using a mitered section. For larger culverts that are not protected by a railing or guard fence, pipe runners arranged either horizontally or vertically shall be used on all SET installations.

Figure 4-2: Typical Culvert End Treatments



Source: TxDOT HDM [4]

The pipe of pipe runner SETs have been proven to be within the tolerance of the entrance loss equation. Therefore, the entrance should be evaluated solely for its shape and the effect of the pipes on the entrance loss equation should be ignored.

4.6.5 CULVERT HYDRAULICS

The hydraulic design of culverts shall be based upon design guidelines set forth by TxDOT, the U.S. Department of Transportation, or other suitable material as approved by the City. Computer programs such as FHWA's "HY-8" may be used, provided that the design engineer provides output tables showing models results and input data.

Values of entrance loss coefficients (Ce) are shown in Table 4-6 based on culvert shape and entrance condition.

Table 4-6: Entrance Loss Coefficients

Entrance Configuration	Ce
CONCRETE PIPE	
Projecting from fill, socket end (groove end)	0.2
Projecting from fill, square cut end	0.5
Headwall or headwall and wingwalls:	-
Socket end of pipe (groove end)	0.2
Square-edge	0.5
Rounded (radius 1/12 D)	0.2
Mitered to conform to fill slope	0.7
End section conforming to fill slope	0.5
Beveled edges, 33.7º or 45º bevels	0.2
Side- or slope-tapered inlet	0.2
CORRUGATED METAL PIPE OR PIPE ARCH	-
Projecting from fill (no headwall)	0.9
Headwall or headwall and wingwalls square-edge	0.5
Mitered to conform to fill slope, paved or unpaved slope	0.7
End section conforming to fill slope	0.5
Beveled edges, 33.7º or 45º bevels	0.2
Side- or slope-tapered inlet	0.2
REINFORCED CONCRETE BOX	-
Headwall parallel to embankment (no wingwalls):	-
Square-edged on 3 edges	0.5
Rounded on 3 edges to radius of 1/12 barrel dimension, or beveled edges on 3 sides	0.2
Wingwalls at 30º to 75º to barrel:	-
Square-edged at crown	0.4
Crown edge rounded to radius of 1/12 barrel dimension, or beveled top edge	0.2
Wingwall at 10º to 25º to barrel: square-edged at crown	0.5
Wingwalls parallel (extension of sides): square-edged at crown	0.7
Side- or slope-tapered inlet	0.2
Source: TxDOT HDM [4]	

There are two categories of flow through culverts: inlet control and outlet control.

a. Inlet Control: The flow is controlled by the cross-sectional area of the culvert, inlet configuration, and headwater depth. Slope, roughness, and length of culvert are of no importance. Nomographs are available for inlet control estimations as proved in Hydraulic Design of Highway Culverts [8].
b. Outlet control: The flow is controlled by the cross-section area of the culvert, inlet configuration, and headwater depth and, slope, roughness and length of culvert. Culverts will be outlet controlled if the culvert slope is relatively flat, the tailwater sufficiently deep, or the culvert is quite long. It is also possible, where the water enters the culvert under inlet control, but the culvert slope, or tailwater conditions cause a hydraulic jump near the outlet. This situation should be avoided because damage can occur to the culvert pipe. Unstable conditions are most likely when the culvert is placed at a near-critical slope.

The design engineer shall calculate both outlet and inlet control conditions and use the more conservative of the two as the design condition.

4.6.6 Culvert Outlet Protection

High discharge velocities from culverts can cause eddies or other turbulence, which could damage unprotected downstream channel banks and roadway embankments. To prevent damage from scour and erosion in these conditions, culvert outlet protection is needed. The outlet protection should extend downstream to a point where non-erosive channel velocities or shear stress are established in accordance with Section 4.5.5 of this manual. The outlet protection should be placed sufficiently high on the adjacent banks to extend 1 foot above the design water surface elevation. All outlet protection shall be designed with an appropriate toe depth. All toes shall be no less than twenty-four inches.

4.6.7 Energy Dissipation

Design of riprap stone protection shall be done in accordance to *HEC 22*. Design of concrete baffles and stilling basins shall be done in accordance with *HEC 14*.

CHAPTER 5 DETENTION FACILITIES

Detention is the storage of runoff for a controlled release during or immediately following a design storm. The detention facility shall be appropriate to the type of development, topography, and amount of control needed.

5.1 General Requirements

All proposed detention facilities must achieve the following requirements:

a. The method(s) of detention shall be appropriate to the type of development, topography, and amount of control needed. Examples of methods include, but are not limited to, the following:
    a. Basins or swales – single or multiple
    b. Check dams in gullies to slow runoff and trap sediment
    c. Contour terracing, improved vegetation cover
b. Parking areas may be used as detention facilities provided that maximum depths of ponding do not exceed eight inches and ponding is in the areas most remotely situated from structures.
c. Stormwater infiltration systems are not permitted for mitigation in any development where there is a potential for pollutants to adversely affect ground water quality (e.g. Edwards Aquifer Recharge Zone).
d. No detention basin shall retain standing water longer than 36 hours unless it is designed and constructed to be a permanent pond with appropriate health, safety and water quality measures. Permanent ponds must comply with all applicable water rights requirements for such a body of water.
e. Detention basins to be excavated shall provide positive drainage through the pond. Consideration should be given to pond slope and erosion protection.
f. Finished floors of adjacent structures should be a minimum of 1 foot above the 100-year water surface in the facility. Facilities should preferably be located such that the invert of the outlet structure is above the 100-year water surface level in the receiving body; but in all cases, facilities shall be designed to function properly during conditions where the outlet is submerged by the tailwater of the receiving stream.
g. Detention facilities shall be designed with one or more outlet structures to allow safe passage of the 100-year post-development design storm runoff. Emergency overflow weirs shall also be required. Overflow weirs shall consider where overflow is directed and where feasible, direct overflows to easements and ROW but shall in no case adversely impact adjacent properties or streams.
h. Weirs, spillways, and outlets shall be protected from erosion with riprap, grouted riprap, or other method of erosion control to protect the structure and downstream channel. Outflows shall be conveyed within proposed property limits or easement to an appropriate receiving drainage facility in a manner such that roadways, private property, buildings, etc. are not damaged.
i. Best management practices shall be used in the event a detention facility empties into another storage facility downstream. The timing of the hydrograph from the detention facility shall be checked against the timing of the receiving storage facility to prevent any increase in the flow rate from the downstream facility.
j. Side slopes of earthen embankments shall be designed for stability and safety, with side slopes of earthen banks shall be 3H:1V or flatter. All constructed stormwater structures of earthen material shall be re-vegetated to mature growth.
k. Maximum water depths over 6 feet shall not be allowed without prior approval from the City. Any detention facility that is classified as a dam by the TCEQ shall conform to the more stringent of rules listed in this manual or the dam safety rules adopted by TCEQ.

l. Earthen embankments of a height greater than 3 feet used to impound a required detention volume must have a minimum top-width of 4 feet, shall contain a non-permeable core, and shall be based on a geotechnical investigation for the site. Compaction of all earthen drainage structures shall be to 90% standard proctor.
m. A maintenance ramp shall be provided for access in detention basin design for periodic desilting and debris removal. Access shall be provided to all ponds and channel maintained by the City, regional drainage facilities, or any other drainage facility designed for drainage of more than one privately maintained single-family lot as follows: ponds and channels shall provide a maintenance access with a width of at least 12 feet and have a vertical grade no steeper than 6H:1V. Access shall be provided within dedicated ROW or within the drainage easement and shall be clearly identified on plans.

   Maintenance schedules and descriptions of maintenance practices for privately maintained single-family residential ponds and channels shall be provided within the plans or as a separate document. Adequate access shall be provided for the maintenance description provided.

n. Basins with permanent storage must include dewatering facilities to provide for maintenance.
o. The design of detention facilities shall include provisions for collecting and removing sediment deposited after collecting and releasing stormwater.
p. Detention ponds and reservoirs shall provide freeboard based on Table 2-4 of this manual for the 100-year storm event measured from top of berm to the 100-year water surface elevation of the pond.

5.2 Design Criteria

The purpose of a stormwater detention basin is to temporarily impound (detain) excess stormwater, thereby reducing peak discharge rates. Therefore, all detention ponds are to be designed to prevent an increase in flow to the existing 2, 10, 25, and 100-year peak runoff leaving a proposed site. The design engineer must use the NRCS unit hydrograph as outlined in Section 3.4 of this manual.

5.3 Outlet Structure Design

To reduce the 2, 10, 25, and 100-year post-developed design storm flows to pre-development levels, a multi-level outlet structure may be required. The required documentation for the design of any detention structures include design hydrographs, calculations of stage-storage-discharge tables, drawings of the basin, spillway, weir and outlet size and location along with necessary erosion control measures. For further guidance for design and construction of outlet structures, the design engineer should reference the Stormwater Detention Outlet Control Structures [9].

5.3.1 Orifices

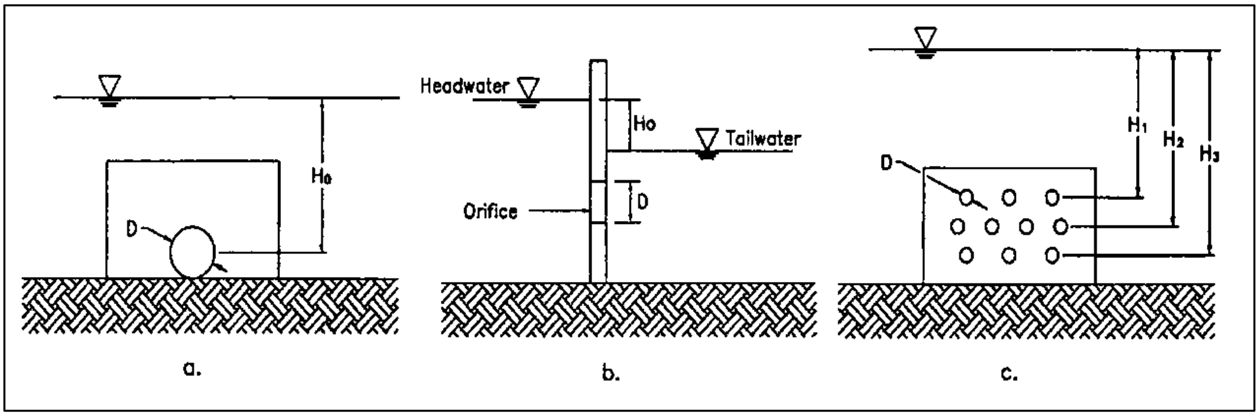
The orifice flow for a single orifice, depicted in Figure 5-1, can be calculated from Equation 5-1.

$$Q = C_0 A_0 (2gH_0)^{0.5} \quad \text{(Equation 5-1)}$$

Where:

Q= Orifice flow rate (cfs)
C_0= Discharge coefficient 0.40-0.60
A_0= Area of orifice (sf)
H_0= Effective head on the orifice measured from the centroid of the opening (ft)
g = Gravitational acceleration = 32.2 ft/s^2

Figure 5-1: Definition Sketch for Orifice Flow



Source: HEC 22 [5]

For orifices discharging as a free outfall, the effective head is measured from the centerline of the orifice to the water surface elevation. For submerged orifices, the effective head is the difference in elevation between the upstream and downstream water surface elevations. A submerged orifice can be seen in Figure 5-1(b).

The discharge coefficient for orifices depend on the entrance conditions and shape of the orifice. For a square-edged orifice with uniform entrance conditions, the discharge coefficient should be 0.6. However, for ragged edged orifices, such as occurring when using an acetylene torch to cut the orifice opening into a corrugate pipe, 0.4 should be used for the discharge coefficient.

Design engineers may analyze pipes with a diameter of 1 foot or less as a submerged orifice as long as H_0/D is greater than 1.5. If the diameter of the pipe is greater than 1 foot, it must be analyzed as a discharge pipe and the design engineer must take into account both headwater and tailwater effects.

When dealing with flow through multiple orifices, as seen in Figure 5-1(c), the sum of the flow through each individual orifice is the total flow through them all. For multiple orifices of the same size and operating under the same effective head, the flow through one orifice can be multiplied by the number of openings to find the total flow.

5.3.2 WEIRS

Weirs are typically one of four types: sharp crested, broad-crested, V-notch, or proportional. The following section provides the required relationships for each type of weir. Design procedures are provided in HEC 22.

5.3.2.1 Sharp Crested Weirs

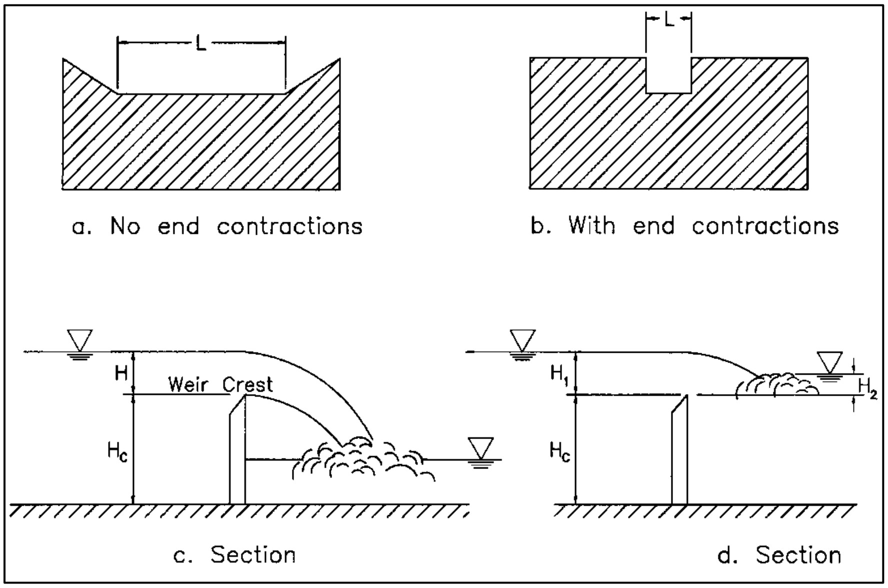
Typical sharp crested weirs are shown in Figure 5-2.

When a sharp crested weir has an end contraction, as shown in Figure 5-2(b), the equation changes, as follows:

$$Q = C_{SCW}(L - 0.2H)H^{1.5} \qquad \text{(Equation 5-4)}$$

The Sharp Crested Weir coefficient varies linearly with the ratio H/H_c and is typically set equal to 3.33 (English units) when the ratio of H/H_c is less than 0.3.

Figure 5-2: Sharp Crested Weirs



Source: HEC 22 [5]

5.3.2.2 Broad-Crested Weir

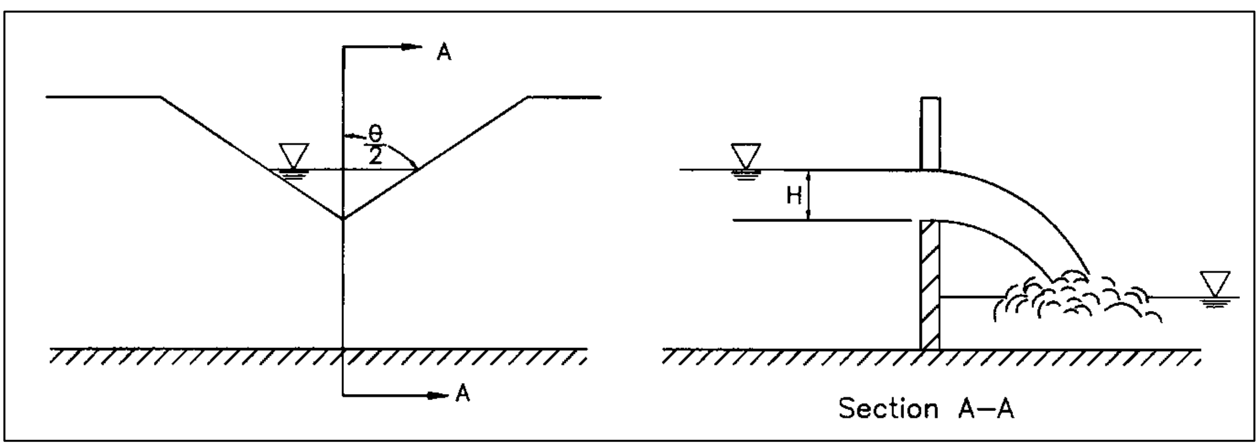
The broad crested weir coefficient is dependent on the breadth of crest of weir and head. Several commonly used broad crested weir coefficients are used for specific cases.

- If the upstream edge of a broad-crested weir is so rounded as to prevent contraction and if the slope of the crest is as great as the loss of head due to friction, flow will pass through critical depth at the weir crest; this gives the maximum C value of 3.09.
- For sharp corners on the broad crested weir, a minimum value of 2.62 should be used.

5.3.2.3 V- Notch Weir

Typical sections for a V-notch weir can be seen in Figure 5-3.

Figure 5-3: V-Notch Weir

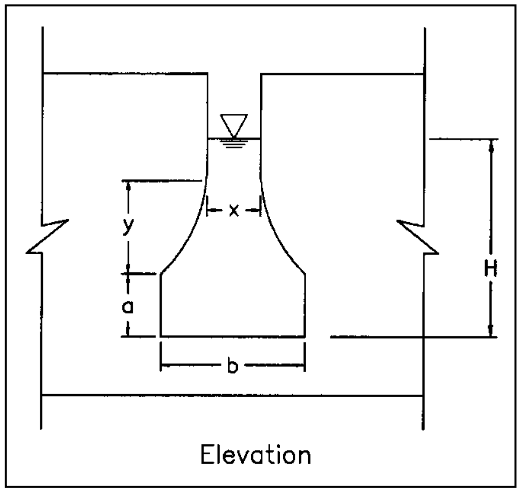


Source: *HEC 22* [5]

5.3.2.4 Proportional Weir

Although more complex to design and construct, a proportional weir has the potential to significantly reduce the required storage volume for a given site. Unlike the other three types of weirs, the proportional weir has a linear head-discharge relationship. The linear relationship evolves from allowing the discharge area to vary non-linearly with head. Dimensions for a proportional weir are shown in Figure 5-4.

Figure 5-4: Proportional Weir Dimensions



Source: *HEC 22* [5]

5.3.3 DISCHARGE PIPES

Discharge pipes may be used as outlet structures for detention basins. An outlet structure utilizing discharge pipes can be designed one of two ways, either as a single or multistage discharge.

A single discharge system consists of a single discharge pipe or culvert. The single discharge system is designed as a simple culvert would be. As in Section 4.6.3 of this manual, the downstream boundary conditions would be applied in the same manner. The end computations would be a stage-discharge curve developed for the full range of flows that the single system may experience. The single pipe does not include a system to carry emergency flows.

A multistage discharge system does include a control structure at the inlet end of the pipe. This inlet control structure must be designed with the full range of flows under consideration. As with the single discharge system, a stage-discharge curve would be developed for all potential flows the system may experience. The design flows will typically be orifice flow through whatever shape the designer has chosen while the higher flows will typically be weir flow over the top of the control structure.

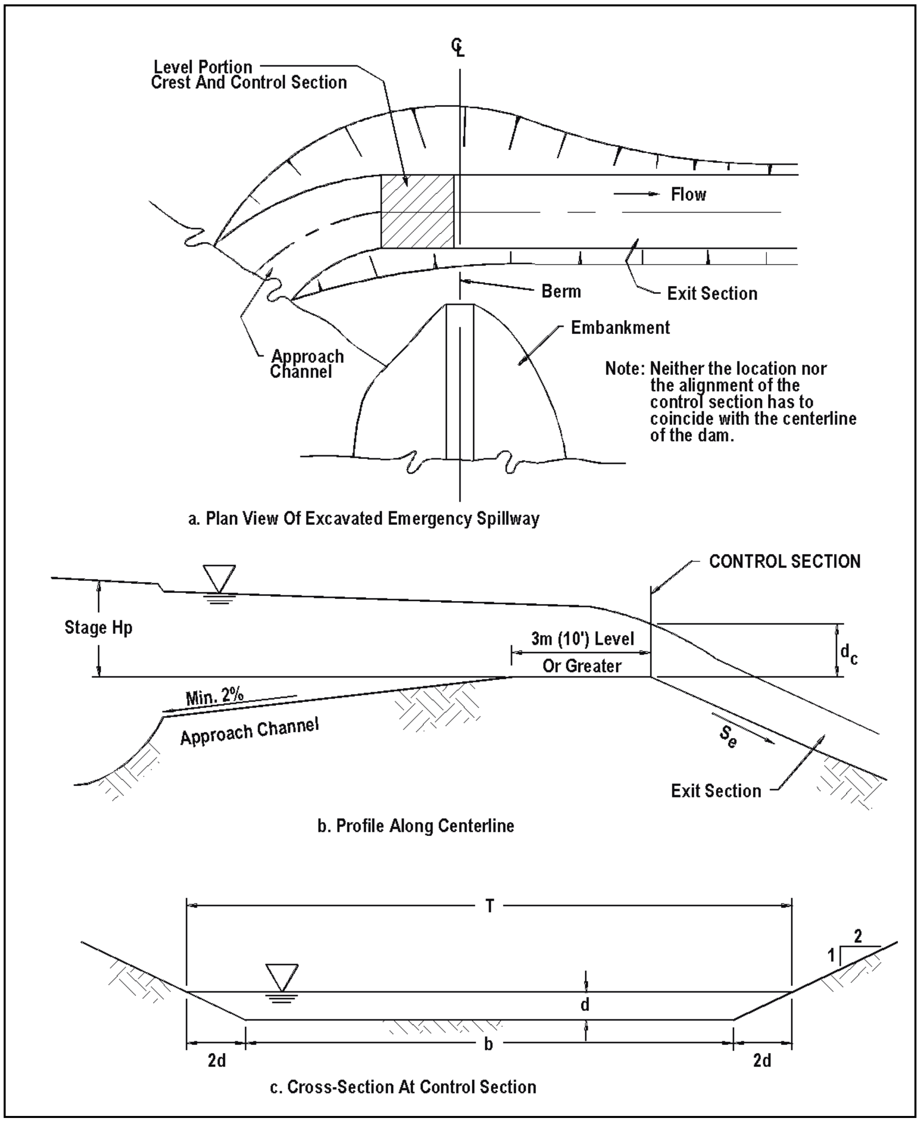
Orifices can be designed as outlined in Section 5.3.1 and weirs can be designed as shown in Section 5.3.2. The pipe must be designed to carry all flows considered in the design of the control structure.

In designing a multistage structure, the designer would first develop peak discharges that must be passed through the facility. The second step would be to select a pipe that will pass the peak flow within the allowable headwater and develop a performance curve for the pipe. Thirdly, the designer would develop a stage-discharge curve for the inlet control structure, recognizing that the headwater for the discharge pipe will be the tailwater that needs to be considered in designing the inlet structure. Last, the designer would use the stage-discharge curve in the basin routing procedure.

5.3.4 EMERGENCY OVERFLOW WEIRS

When storms occur, resulting in storm flows exceeding the design discharge of the detention basin, emergency overflow weirs allow a controlled relief of the excess water. Typically, an emergency overflow weir has a trapezoidal cross-section design for its constructability. The typical emergency overflow weir is shown in Figure 5-5. Emergency overflow weirs that do not incorporate a spillway should be treated as a broad-crested weir.

Figure 5-5: Emergency Spillway Design Schematic



Source: *HEC 22* [5]

The discharge coefficient varies as a function of the bottom width of the spillway and the effective head on the spillway. Design parameters for the relationship are included in HEC 22.

The critical slopes are based upon an assumed Manning's coefficient of 0.040 for turf cover of the spillway. For a paved spillway the Manning's coefficient should be 0.015. The Manning's coefficient is dependent on the spillway material and must be adjusted according to the design developed by the design engineer.

CHAPTER 6 WATER QUALITY CONTROLS

Stormwater can have a significant impact on water quality in creeks and rivers within and downstream of the City. To maintain the integrity of the natural environment, the City requires controls to remove suspended particulate matter and associated constituents such as bacteria, nutrients, and metals from stormwater discharges.

6.1 Applicability

Permanent water quality controls for all developments within the City shall comply with the latest TCEQ published rules and technical design guidance. The selected BMP or combination of BMPs must reduce the increase in total suspended solids (TSS) load associated with development by at least 80 percent. Single-family residential developments with less than 20% impervious cover are not required to treat stormwater discharges. For developments within the Edwards Aquifer Recharge Zone, TCEQ approval is required.

6.2 Design Criteria

Permanent water quality BMPs shall be designed to provide adequate treatment of impervious cover in the City's Jurisdiction. The selection and sizing of BMPs shall follow the procedures outlined in the latest version of the TCEQ Report Publication RG-348 [10], as amended. All BMPs included in the errata sheet and addendums are accepted for use.

6.3 Maintenance

The maintenance requirements for BMPs as defined by TCEQ must be followed for all BMPs and is the responsibility of the property owner. A copy of the recorded maintenance plan, as required by TCEQ, shall be provided to the City. Documentation of annual inspections required by the City or TCEQ shall be submitted to the City each year. Changes in the ownership and responsibility provided to TCEQ shall also be provided to the City.

CHAPTER 7 EROSION CONTROL MEASURES

Private property owners, developers, or builders shall be accountable for erosion of their property or construction site which results in measurable accumulation of sedimentation in dedicated streets, alleys, waterways, or other properties. Sediment carried by stormwater runoff shall be prevented from entering storm drain systems and natural watercourses.

7.1 General Requirements

a. Maximum use shall be made of vegetation to minimize soil loss. Vegetation measures should begin as soon as possible during construction in order to allow for establishment at construction termination.
b. Natural vegetation should be retained wherever possible including trees. Where inadequate natural vegetation exists or where it becomes necessary to remove existing natural vegetation, temporary controls should be installed promptly to minimize soil loss and ensure that erosion and sedimentation does not occur.
c. During construction, erosion controls shall be used to slow drainage flow rate and prevent downstream sedimentation.
d. Erosion control elements should be implemented as soon as practical in the development process.
e. Waste or disposal areas and construction roads should be located and constructed in a manner that will minimize the amount of sediment entering streams.
f. Frequent fording of live streams will not be permitted; therefore, temporary bridges or other structures shall be used wherever an appreciable number of crossings of a stream are necessary.
g. When work areas or material sources are located in or adjacent to live streams, such areas shall be separated from the stream by a dike or other barrier to keep sediment from entering a flowing stream. Care shall be taken during the construction and removal of such barriers to minimize the sediment transport into a stream.
h. Should preventative measures fail to function effectively, the applicant shall act immediately to bring the erosion and/or siltation under control by whatever additional means are necessary.
i. Erosion control devices shall be placed to trap any losses from stockpiled topsoil. Some acceptable forms of site erosion control devices include, but are not limited to, silt fences, silt traps, and geotextiles. Hay bales are not permitted.
j. The selection and timing of the installation of erosion controls shall be based upon weather and seasonal conditions that could make certain controls not practicable.
k. Vegetation used for vegetative cover shall be suitable for local soil and weather conditions. Ground cover plants shall comply with listings from the Texas Agricultural Extension Service.
l. Stripping of vegetation from project sites shall be phased so as to expose the minimum amount of area to soil erosion for the shortest possible period of time. Phasing shall also consider the varying requirements of an erosion control plan at different stages of construction and shall include the establishment of new vegetation or permanent erosion control measures.
m. SWPPP shall follow TCEQ rules.

7.2 Edwards Aquifer

Development and redevelopment located over the Edwards Aquifer regulatory zones shall comply with the latest TCEQ published rules and technical design guidance for the Edwards Aquifer in accordance with 30 TAC Chapter 213 (Edwards Aquifer Rule) in addition to the provisions and requirements of TPDES General Permit Number TXR150000.

7.3 Temporary Erosion Control Measures (used during construction)

Erosion control and restoration measures shall be designed in conformance with the methods established by the TPDES General Permit Number TXR150000 regardless of disturbed acreage. TCEQ Report Publication RG-348 outlines the selection and design of temporary erosion control and sediment control measures.

7.3.1 Maintenance and Monitoring

Required temporary erosion control measures are to be installed prior to commencing construction and shall remain in place until vegetation is established and the construction area is stabilized. During the course of construction, the property owner is responsible for maintaining the integrity of all temporary erosion control measures. Maintenance requirements for the BMPs are included in TCEQ RG-348. In general, the site and vicinity shall be clear of debris and sediment. The property owner is responsible for cleaning and removing all sediment discharged from the site during the construction at the direction of the City.

7.3.2 Final Acceptance

All site related items must be complete in accordance with this Drainage and Erosion Control Design Manual prior to occupancy of the last building on a site. A Letter of Concurrence is required from the Engineer certifying completion of all stormwater detention and water quality management facilities prior to final acceptance.

7.4 Permanent Erosion Control Measures

Natural drainage patterns shall be preserved whenever possible. Drainage patterns should be designed to prevent erosion, maintain filtration and recharge of local seeps and springs, and attenuate the harm of contaminants collected and transported by storm water.

7.4.1 Cut/Fill Limits

In order to reduce stormwater runoff, resulting in erosion, sedimentation and conveyance of nonpoint source pollutants, the layout of the street network, lots and building sites shall, to the greatest extent possible, be sited and aligned along natural contour lines, and shall minimize the amount of cut and fill on slopes in order to minimize the amount of land area disturbed during construction. The maximum cut and fill limits are shown in Table 7-1.

Table 7-1: Maximum Cut and Fill Limits

Slope	Open Cuts and Fills	Closed Cuts	Closed Fill
0 - 15%	3 feet	20 feet	6 feet
15 - 25%	1 foot	15 feet	6 feet
25% - 35%	0 feet	10 feet	6 feet
> 35%	0 feet	0 feet	0 feet

7.4.2 Stream Bank Erosion

Erosion control will be provided along streams and drainage channels. Where bank stabilization or other erosion protection measures are required to protect streams and channels, mitigation measures shall be detailed and calculations provided.

Appendix A: References

[1] W. Asquith, "Depth-Duration-Frequency of Precipitiation for Texas," US Geological Survey Water Resources Investigations Report 98-4044, Austin,TX, 1998.

[2] "Urban Hydrology for Small Watersheds - Technical Release 55," Natural Resources Conservation Services, Washington, D.C., 1986.

[3] City of Austin, Drainage Criteria Manual, Austin, 2014.

[4] Texas Department of Transportation, "Hydraulic Design Manual," Austin, TX, 2016.

[5] US Department of Transportation, Federal Highway Adminstration, "Urban Drainage Design Manual, Hydraulic Engineering Circular No. 22," 3rd Edition, Washington, D.C, 2009.

[6] US Department of Transportation, Federal Highway Adminstration, "Design of Roadway Channels with Flexible Linings, Hydraulic Engineering Circular No. 15," 3rd Edition, Washington, D.C., 2005.

[7] US Department of Transportation, Federal Highway Administration, "Hydraulic Design of Energy Dissipaters for Culverts and Channels, Hydraulic Engineering Circular No. 14," 3rd Edition, Washington, D.C., 2006.

[8] US Department of Transportation, Federal Highway Adminstration, "Hydraulic Design of Highway Culverts, Hydraulic Design Series No 5," 3rd Edition, Washington, D.C., 2012.

[9] J. Jones, "Stormwater Detention Outlet Control Structures," *Great Works on Urban Water Resources,* Vols. 1962-2001, pp. 857-887, 2006.

[10] TCEQ, "Complying with Edwards Aquifer Rules Technical Guidance on Best Management Practices," Austin, Texas, July 2005.

Appendix B: Definition of Terms

100-year Event: Event (rainfall or flood) that statistically has a one percent chance of being equaled or exceeded in any given year.

Abutment: A wall supporting the end of a bridge or span, and sustaining the pressure of the abutting earth.

Apron: A floor or lining of concrete, timber, or other suitable material at the toe of a dam, entrance or discharge side of spillway, a chute, or other discharge structure, to protect the waterway from erosion from falling water or turbulent flow.

Backwater: The rise of the water level upstream due to an obstruction or constriction in the channel.

Baffles: Deflector vanes, guides, grids, gratings, or similar devices constructed or placed in flowing water to: (a) check or effect a more uniform distribution of velocities; (b) absorb energy; (c) divert, guide, or agitate the liquids; and (d) check eddy currents.

Calibration: Process of checking, adjusting, or standardizing operating characteristics of instruments and model appurtenances on a physical model or coefficients in a mathematical model. The process of evaluating the scale readings of an instrument in terms of the physical quantity to be measured.

Channel: Any path of concentrated flow that conveys storm runoff from a drainage area greater than 128 acres.

Channel stability: A condition in which a channel neither degrades to the degree that structures, utilities or private property are endangered, nor aggrades to the degree that flow capacity is significantly diminished as a result of one or more storm runoff events or moves laterally to the degree that adjacent property is endangered.

Closed cut: Excavations that prevent erosion by some permanent erosion control structure such as a reinforced concrete retaining wall, dry stacked stone, or other permanent erosion control device.

Closed fill: Embankments that prevent erosion by some permanent erosion control structure such as a reinforced concrete retaining wall, dry stacked stone, or other permanent erosion control device.

Conduit: Any open or closed device for conveying flowing water.

Critical Flow: The state of flow for a given discharge at which the specific energy is a minimum with response to the bottom of the conduit.

Crown: (a) The highest point on a transverse section of conduit; (b) the highest point of a roadway cross section.

Culvert: Large pipe or other conduit through which a stormwater flows under a road or street.

Curb Inlet: A vertical opening in a curb through which the gutter flow passes. The gutter may be undepressed or depressed in the area of the curb opening.

Degradation: The progressive general lowering of a stream channel by erosion.

Depression Storage: Collection and storage of rainfall in natural depressions (small puddles) after exceeding infiltration capacity of the soil.

Design Storm. The storm which is used as the basis for design, i.e., against which the structure is designed to provide a stated degree of protection or other specified result.

Detention: The storage of storm runoff for a controlled release during or immediately following the design storm.

a. **Off-site detention:** A detention pond located outside the boundary of the area it serves.

b. **On-site detention:** A detention pond which is located within and serves only a specific site or subdivision.

c. **On-stream detention:** Detention facilities provided to control excess runoff based on a watershed wide hydrologic analysis.

Developed land: Any lot or parcel of land occupied by any structure intended for human occupation, including structures intended for commercial or industrial enterprise.

Developer: Any individual, estate, trust, receiver, cooperative association, club, corporation, company, firm, partnership, joint venture, syndicate or other entity engaging in platting, subdivision, filling, grading, excavating, or construction of structures.

Disturbed area: Area impacted by construction including all vehicle access, material storage, building construction, pavement, and necessary workspace for construction

Downstream capacity: The ability of downstream drainage facilities to accept and safely convey runoff generated upstream.

Drainage basin: The storm water catchment area above a point on a channel to which waters drain and collect. Watershed has the same meaning.

Drainage easement: A platted area reserved for the primary purpose of stormwater drainage and maintenance.

Drainage System: Drainage systems shall include streets, alleys, storm drains, drainage channels, culverts, bridges, overflow swales, and any other facility through which or over which storm water flows.

Drop Inlet: A storm drain intake structure typically located in unpaved areas. The inlet may extend above the ground level with openings on one or more sides or it may be flush with the ground with a grated cover.

Entrance Head: The head required to cause flow into a conduit or other structure; it includes both entrance loss and velocity head.

Entrance Loss: Head lost in eddies or friction at the inlet to a conduit, headwall or structure.

Erosion control: Treatment measures for the prevention of damages due to soil movement and to deposition.

Excavation: Digging and removal of earth by mechanical means.

Fill: The placement of material such as soil or rock to replace existing material, or to create an elevated embankment. Fill also refers to the material which is placed.

Flood or Flooding: A general and temporary condition of inundation of normally dry land areas by surface runoff. The 100-year flood is the flow rate with a 1% probability of being equaled or exceeded in any one year.

Flood Hazard Area: Area subject to flooding by 100-year frequency floods.

Floodplain: Geographically the entire area subject to flooding. In usual practice, it is the area subject to flooding by the 100-year frequency flood. In this manual, the "100-year floodplain" refers to the floodplain resulting from a 100-year flood based on ultimate watershed development conditions. The "FEMA floodplain" shall refer to the area subject to flooding resulting from the 100-year flood for current watershed development conditions.

Freeboard: The distance between the normal operating level and the top of the side of an open conduit left to allow for wave action, floating debris, or any other condition or emergency without overtopping the structure.

Frequency: Average recurrence interval of a given storm event over long periods of time.

Froude Number: A flow parameter which is a measure of the extent to which gravitational action affects the flow. A Froude number greater than one indicates supercritical flow and a value less than one indicates subcritical flow.

Fully developed watershed: A hydrologic condition in which all areas upstream and downstream of a point in question are assumed completely developed, including any undeveloped areas, which are assumed to be developed in accordance with development densities established by the City

Gabion: A wire basket containing earth or stones, deposited with others to provide protection against erosion.

Grade: (a) The inclination or slope of a channel, canal, conduit, etc., or natural ground surface, usually expressed in terms of the percentage of number of units of vertical rise (or fall) per unit of horizontal distance. (b) The elevation of the bottom of a conduit, canal, culvert, sewer, etc. (c) The finished surface of a canal bed, road bed, top of an embankment, or bottom of excavation.

Grading: Any movement of soil, rock, or vegetation by artificial means, to include any or all of the following acts: clearing, grubbing, excavating, placement of fill material, or grading of land.

Grate Inlet: An opening in the gutter covered by one or more grates through which the water falls. As with all inlets, grated inlets may be either depressed or undepressed and may be located either on a continuous grade of in a sump.

Gutter: A generally shallow waterway adjacent to a curb, used or suitable for drainage of water.

Headwater: (a) The upper reaches of a stream near its sources; (b) the region where ground waters emerge to form a surface stream; (c) the water upstream from a structure.

Hydraulic Control: The hydraulic characteristic which determines the stage discharge relationship in a flowing stream or conduit. The control is usually critical depth, tailwater depth or uniform depth.

Hydraulic Grade Line: A line representing the pressure head available and elevation head at any given point within the system.

Impervious: A term applied to a material through which water cannot pass, or through which water passes with great difficulty.

Infiltration: (a) The entering of water through the interstices or pores of a soil or other porous medium; (b) the quantity of groundwater which leaks into a sanitary or combined sewer or drain through defective joints, breaks or porous walls; (c) The absorption of water by soil, either as it falls as precipitation or from a stream flowing over the surface.

Inlet: (a) An opening into a storm sewer system for the entrance of surface storm runoff, more completely described as a storm sewer inlet; (b) a structure at the diversion end of a conduit; (c) the upstream connection between the surface of the ground and a drain or sewer, for the admission of surface or storm water.

Interception: As applied to hydrology, refers to the process by which precipitation is caught and held by foliage, twigs, and branches of trees, shrubs and buildings, never reaching the surface of the ground, and then lost by evaporation.

Invert: The floor, bottom, or lowest portion of the internal cross-section of a conduit. Used particularly with reference to storm drains, sewers, tunnels, channels and swales.

Lag Time: In hydrograph analysis lag time is the time from the centroid of the mass of excess rainfall to the peak of the runoff hydrograph. See Time of Concentration.

Lining: The material placed on the sides and/or bottom of a ditch, a channel, and/or a reservoir to prevent or reduce seepage of water through the sides and bottom and/or to prevent erosion.

Maintenance: The cleaning, shaping, grading, repair, and minor replacement of drainage, flood control and erosion facilities, but not including the cost of power consumed in the normal operation of pump stations.

Manning's Coefficient: The coefficient of friction used in the Manning Equation to describe the surface roughness characteristics of a channel, floodplain, or sheet flow surface.

Manning's Equation: A uniform flow equation used to relate velocity, hydraulic radius and the energy gradient.

NRCS Runoff Curve Number: Index number used by the Soil Conservation Service as a measure of the tendency of rainfall to run off into streams rather than evaporate or infiltrate.

Open Channel: The general term for a conduit in which water flows with a free surface.

Open cut: Excavations that will not contain any form of permanent erosion control other than planting of ground cover.

Open fill. Embankments that will not contain any form of permanent erosion control other than planting of ground cover.

Orifice: (a) An opening with closed perimeter and regular form in a plate, wall, or partition, through which water may flow; (b) the end of a small tube, such as a Pitot tube, piezometer, etc.

Peak Flow: The maximum rate of runoff during a given runoff event.

Permeability: The property of a material which permits movement of water through it when saturated and actuated by hydrostatic pressure.

Pervious: Applied to a material through which water passes relatively freely.

Post development: The condition of the given site and drainage area after the anticipated development has taken place.

Precipitation: Any moisture that falls from the atmosphere, including snow, sleet, rain and hail.

Preliminary Drainage Plan: A schematic layout of the drainage system required for platting. The Preliminary Drainage Plan shall show locations of channels, storm sewers, detention structures, floodplain, floodway, and associated drainage easements at a minimum.

Pre-development: The condition of the given site and drainage area prior to development.

Rainfall Duration: The length of time over which a single rainfall event occurs.

Rainfall Intensity: The rate of rainfall, usually in inches or millimeters per hour.

Rational Formula: A traditional means of relating runoff from a drainage basin to the intensity of the storm rainfall, the size of the basin, and the characteristics of the basin (such as land use, impervious cover).

Reach: Any length of river or channel. Normally refers to sections which are uniform with respect to discharge, depth, area or slope, or sections between gagging stations.

Return Period: The average interval of time within which a given event is statistically predicted to be equaled or exceeded once.

Riprap (Revetment). Forms of bank channel protection, usually using rock or concrete. Riprap is a term sometimes applied to stone which is dumped rather than placed more carefully.

Right-of-way (ROW). A strip of land dedicated for public streets and/or related facilities, including utilities, drainage systems and other transportation uses.

Runoff: That part of the precipitation that exceeds the precipitation lost to evaporation, transpiration, interception, depression storage, and infiltration and reaches a stream or storm drain.

Runoff Coefficient: A decimal number used in the Rational Formula, which defines the runoff characteristics (i.e., land use impervious cover) of the drainage area under consideration. It may be applied to an entire drainage basin as a composite representation or it may be applied to a small individual area such as one residential lot.

Scour: The erosive action of running water, in streams or channels, in excavating and carrying away material from the bed and banks.

Sediment: Material of soil and rock origin transported, carried, or deposited by flowing water.

Sidewalk: A paved area within the street right-of-way specifically designed for pedestrians and/or bicyclists.

Soffit: The top of the inside of a pipe. In a pipe, the uppermost point on the inside of the structure.

Spillway: A waterway in or about a dam or other hydraulic structure for the escape of excess water.

Stilling Basin: Pool of water conventionally used, as part of a drop structure or other structure, to dissipate energy.

Subcritical Flow: Relatively deep, tranquil flow with low flow velocities. The Froude Number is less than 1.0 for subcritical flow conditions.

Supercritical Flow: Relatively shallow, turbulent flow with high velocities. The Froude Number is greater than 1.0 for supercritical flow conditions.

Tailwater: The depth of flow in the stream directly downstream of a drainage facility or other man made control structure.

Time of Concentration: The estimated time in minutes required for runoff to flow from the most hydraulically remote section of the drainage area to the point at which the flow is to be determined. Hydraulically remote refer to the travel path with the longest flow travel time, not necessarily the longest linear distance.

Ultimate Development: The condition of the watershed after the entire watershed has undergone development.

Unit Hydrograph: The direct runoff hydrograph resulting from one inch of precipitation excess, distributed uniformly over a watershed for a specified duration.

Watershed: The area contributing storm runoff to a stream or drainage system. Other terms are drainage area, drainage basin, and catchment area.